Merging Rate of Dark Matter Halos: Evolution and Dependence on Environment

Stefan Gottlöber
Astrophysical Institute Potsdam, An der Sternwarte 16, D-14482 Potsdam, Germany

Anatoly Klypin and Andrey V. Kravtsov
Astronomy Department, NMSU, Dept.4500, Las Cruces, NM 88003-0001, USA

Abstract. We discuss the impact of the cosmological environment on the evolution of dark matter halos using a high-resolution simulation within a spatially flat ΛCDM cosmology.

Keywords: cosmology, numerical simulations, galaxy formation

1. Introduction

It is generally believed that cold dark matter (DM) dominates the mass in the Universe and significantly affects both the process of galaxy formation and the large-scale distribution of galaxies. Here we present results of a study of the formation and the evolution of the DM component of galaxies, DM halos. The structure of the halos depends on the environment (e.g., Avila-Reese et al. 1999), so that the properties of galaxies are also expected to depend on the cosmological environment. For our analysis we use a low-density flat cosmological model with cosmological constant Λ, which have been proved to be very successful in describing most of the observational data at both low and high redshifts: $\Omega_M = 1 - \Omega_\Lambda = 0.3$, $\sigma_8 = 1$, $H_0 = 70$ km/s/Mpc, $t_0 \approx 13.5$ Gyrs.

2. Numerical Simulations

In order to study the statistical properties of halos and to have a sufficient mass resolution we have chosen a simulation box of $60h^{-1}$Mpc with 256^3 cold dark matter particles (particle mass of $1.1\times10^9 h^{-1}\mathrm{M}_\odot$). Using the Adaptive Refinement Tree (ART) code (Kravtsov, Klypin & Khokhlov 1997) we reached a force resolution of $\approx 2h^{-1}$ kpc in high density regions.

Identification of halos in dense environments and reconstruction of their evolution is a challenge. Any halo finding algorithm has to deal

with difficult "decision-making" situations, in particular when many gravitationally bound halos are moving within a large dense object (a galaxy cluster or a group). We use an algorithm described in Klypin et al. (1999). We characterize each halo by its mass and the maximum circular velocity $v_{circ} = \sqrt{GM/R}$. This quantity is more meaningful observationally and can be numerically measured more easily and more accurately than mass. The halo samples are complete for halos with $v_{circ} \gtrsim 100$ km/s (Gottlöber et al. 1999). Here we consider only more massive halos with circular velocities $v_{circ} > 120$ km/s. The limit on the circular velocity is relaxed at high redshifts to allow identification of small progenitors of present-day halos. At $z = 0$ we have detected 4193 halos in our simulation, which corresponds to a halo number density of $0.019 h^3 \mathrm{Mpc}^{-3}$.

For each halo in our $z = 0$ sample we have constructed a complete evolution tree over up to 23 time moments approximately regular in time distributed between $z = 0$ and $z = 10$. The procedure of progenitor identification is based on the comparison of lists of particles belonging to the halos at different moments both back and forward in time (Gottlöber et al 1999). The epoch at which the halo has been identified for the first time depends on our assumption of thresholds of the circular velocity ($v_{circ} > 50$km/s) and mass (minimum of 40 bound particles) for the progenitors of our halos at $z > 0$.

3. Environment of Halos

In order to find the cosmological environment of each of the 4193 halos we run a friend-of-friend analysis over the dark matter particles with a linking length of 0.2 times the mean interparticle distance. By this procedure we find clusters of dark matter particles with an overdensity of ≈ 200. The virial overdensity in the ΛCDM model under consideration is ≈ 330, which corresponds to a linking length of 0.17. Therefore, the objects which we find are slightly larger than the objects at the virial overdensity. We have increased the linking length because we found that halos, which are outside, but close to a cluster, are affected by the cluster.

For each of the halos at $z = 0$ we find the cluster of dark matter particles to which the halo belongs. We call the halo a cluster galaxy if the halo belongs to a particle cluster with a total mass larger than $10^{14} h^{-1} \mathrm{M}_\odot$. We call it an isolated galaxy if only one halo belongs to the object at overdensity 200. The rest of halos are called group galaxies. By this definition pairs of galaxies are also handled as groups. This increases slightly the number of galaxies in "groups".

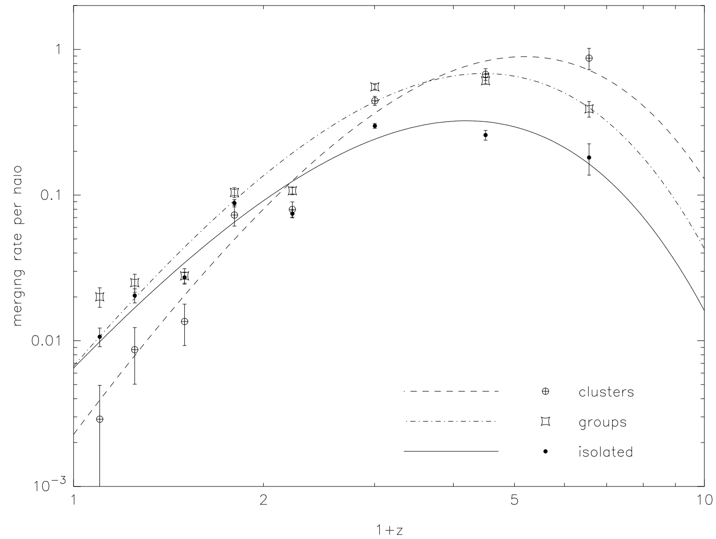

Figure 1. Merging rate per halo and Gyr for isolated halos, halos in clusters, and halos in groups (different symbols). Curves are analytical fits of the form $(1+z)^{\beta}\exp(-0.6(1+z))$. Halos in clusters had much higher merging rates at high redshifts well before the formation of clusters. At $z=0$ merging rates in clusters are very low, but are still relatively high inside groups.

With the procedure described above we find at $z=0$ that there are 401 cluster galaxies (9.6%), 1247 galaxies in groups (29.7%), and 2545 isolated galaxies (60.7%). If we consider objects of virial overdensity, the number of cluster and group galaxies decreases to 6.5% and 25.6% and 67.9% of galaxies become "isolated". For comparison see also Avila-Reese et al. (1999).

4. Merging Rate of Halos

The mass of a halo increases due to accretion and merging. However, interacting halos may exchange and lose mass. We calculate the relative mass growth per time interval $(M_1-M_2)/M_2/(t_2-t_1)$, where time is in units of 10^9 years. If it is larger than 0.35, we call this a major-merging event. Note that according to this definition, we calculate the *total* change of mass, not merging with a large halo.

We found that 28% of the cluster halos, 29% of the group halos and 52% of the isolated halos never underwent a major-merging event. Fig. 1 presents the number of major-merging events – the merging rate – of halos in different environments. We show the merging rate averaged over three (two at $z>2$) subsequent time intervals. The error bars are $\sqrt{N}$ errors for the number of events detected. The three points

for merging inside clusters at $z = 0.1,\ 0.25$, and 0.5 come from 1, 3, and 4 events, respectively. The points in the figure can be fitted by a curve $\alpha\ (1+z)^{\beta}\ \exp(\gamma(1+z))$ with $\alpha = -2.1,\ -1.6,\ -1,6$ and $\beta = 3.1,\ 2.8,\ 2.5$ for cluster, group, and isolated halos, respectively. The exponential dilution is the same for all types, $\gamma = -0.6$. It is mainly due to the fact that at $z > 4$ we are rapidly loosing the halo progenitors due to mass resolution. The position and high of the maxima as well as the slope depend slightly on the chosen threshold for definition of major merging events, but the relative position of the curves remains practically constant.

The higher probability of major-merging that cluster and group halos had in the past is due to the higher density in regions, where cluster and groups were to form. Note that clusters have not yet existed at that time. As clusters with large internal velocities form, merging rate drastically decreases. There are almost no major-merging events of cluster halos in the recent past. Those very few events have probably happened just outside the clusters before the mergers fell in the clusters. The probability of recent major-merging is almost the same for isolated galaxies and for group galaxies. It is very different in the past: the merging of galaxies, which end in clusters, was much higher than for isolated galaxies.

Acknowledgements

This work was funded by the NSF and NASA grants to NMSU, and collaborative NATO grant CRG 972148. SG acknowledges support from Deutsche Akademie der Naturforscher Leopoldina with means of the Bundesministerium für Bildung und Forschung grant LPD 1996.

References

V. Avila-Reese, C. Firmani, A. Klypin, A. V. Kravtsov. Density profiles of dark matter haloes: diversity and dependence on environment. *MNRAS*, accepted, astro-ph/9906260, 1999.

S. Gottlöber, A. A. Klypin, A. V. Kravtsov. Halo evolution in a cosmological environment. In *ASP Conference Series Vol. 176, Observational Cosmology: The Development of Galaxy Systems*, Eds.: G. Giuricin, M. Mezetti, P. Saluccip, 418–429, 1999.

A. A. Klypin, S. Gottlöber, A. V. Kravtsov, A. M. Khokhlov. Galaxies in N-body Simulations: Overcoming the Overmerging Problem. *Astrophysical Journal*, 516: 530–551, 1999.

A. V. Kravtsov, A. A. Klypin, A. M. Khokhlov. Adaptive Refinement Tree: A new high-resolution N-body code for cosmological simulations. *Astrophysical Journal Supplement Series*, 111: 73–94, 1997.